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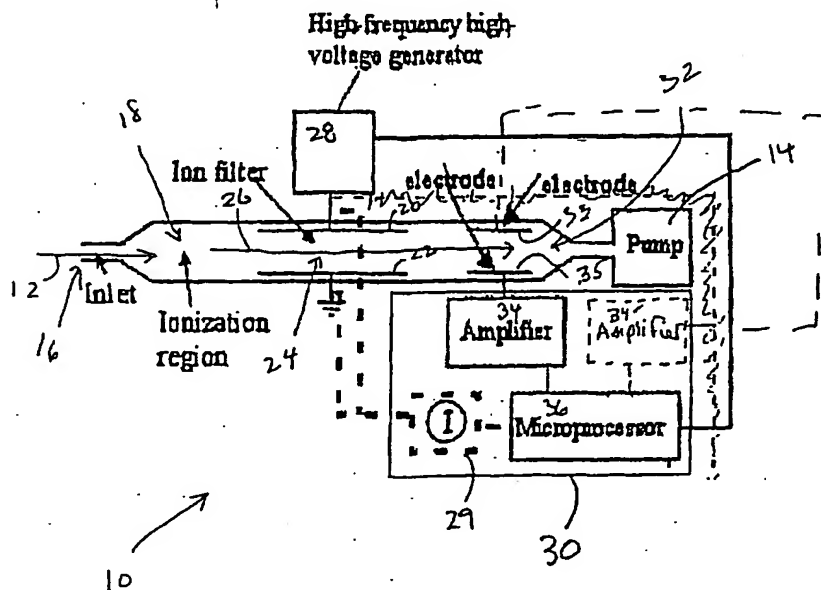
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(54) Title: MICROMACHINED FIELD ASYMMETRIC ION MOBILITY FILTER AND DETECTION SYSTEM



(57) Abstract: A micromechanical field asymmetric ion mobility filter (24) for a detection system includes a pair of spaced substrates defining between them a flow path between a sample inlet (16) and an outlet; an ion filter disposed in the path and including a pair of spaced filter electrodes (20, 22), one electrode associated with each substrate; and an electrical controller (30) for applying a bias voltage and an asymmetric periodic voltage across the ion filter electrodes for controlling the paths of ions through the filter.

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MICROMACHINED FIELD ASYMMETRIC ION MOBILITY FILTER AND DETECTION SYSTEM

FIELD OF INVENTION

This invention relates to a Field Asymmetric Ion Mobility (FAIM) filter, and more particularly, to a micromachined FAIM filter and spectrometer.

BACKGROUND OF INVENTION

The ability to detect and identify explosives, drugs, chemical and biological agents as well as air quality has become increasingly more critical given increasing terrorist and military activities and environmental concerns. Previous detection of such agents was accomplished with conventional mass spectrometers, time of flight ion mobility spectrometers and conventionally machined FAIM spectrometers.

Mass spectrometers are very sensitive, highly selective and provide a fast response time. Mass spectrometers, however, are large and require significant amounts of power to operate. They also require a powerful vacuum pump to maintain a high vacuum in order to isolate the ions from neutral molecules and permit detection of the selected ions, and are also very expensive.

Another spectrometric technique which is less complex is time of flight ion mobility spectrometry which is the method currently implemented in most portable chemical weapons and explosives detectors. The detection is based not solely on mass, but on charge and cross-section of the molecule as well. However, because

of these different characteristics, molecular species identification is not as conclusive and accurate as the mass spectrometer. Time of flight ion mobility spectrometers typically have unacceptable resolution and sensitivity limitations when attempting to reduce their size, that is a drift tube length less than 2 inches. In time of flight ion mobility, the resolution is proportional to the length of the drift tube. The longer the tube the better the resolution, provided the drift tube is also wide enough to prevent all ions from being lost to the side walls due to diffusion. Thus, fundamentally, miniaturization of time of flight ion mobility systems leads to a degradation in system performance. While these devices are relatively inexpensive and reliable, they suffer from several limitations. First, the sample volume through the detector is small, so to increase spectrometer sensitivity either the detector electronics must have extremely high sensitivity, requiring expensive electronics, or a concentrator is required, adding to system complexity. In addition, a gate and gating electronics are usually needed to control the injection of ions into the drift tube.

FAIM spectrometry was developed in the former Soviet Union in the 1980's. FAIM spectrometry allows a selected ion to pass through a filter while blocking the passage of undesirable ions. Conventional FAIM spectrometers are large and expensive, e.g., the entire device is nearly a cubic foot in size and costs over \$25,000. These systems are not suitable for use in applications requiring small detectors. They are also relatively slow, taking as much as one minute to produce a complete spectrum of the sample gas, are difficult to manufacture and are not mass

producible.

BRIEF SUMMARY OF THE INVENTION

It is therefore an object of this invention to provide a FAIM filter and detection system which can more quickly and accurately control the flow of selected ions to produce a sample spectrum than conventional FAIM devices.

It is a further object of this invention to provide such a filter and detection system which can detect multiple pre-selected ions without having to sweep the bias voltage.

It is a further object of this invention to provide such a filter and detection system which can even detect selected ions without a bias voltage.

It is a further object of this invention to provide such a filter and detection system which can detect ions spatially based on the ions' trajectories.

It is a further object of this invention to provide such a filter and detection system which has a very high resolution.

It is a further object of this invention to provide such a filter and detection system which can detect selected ions faster than conventional detection devices.

It is a further object of this invention to provide such a filter and detection system which has a sensitivity of parts per billion to parts per trillion.

It is a further object of this invention to provide such a filter and detection system which may be packaged in a single chip.

It is further object of this invention to provide such filter and detection system

which is cost effective to implement and produce.

The invention results from the realization that an extremely small, accurate and fast FAIM filter and detection system can be achieved by defining a flow path between a sample inlet and an outlet using a pair of spaced substrates and disposing an ion filter within the flow path, the filter including a pair of spaced electrodes, one electrode associated with each substrate and a controller for selectively applying a bias voltage and an asymmetric periodic voltage across the electrodes to control the path of ions through the filter.

The invention results from the further realization that by providing an array of filters, each filter associated with a different bias voltage, the filter may be used to detect multiple selected ions without sweeping the bias voltage.

The invention results from the further realization that by varying the duty cycle of the periodic voltage, no bias voltage is required.

The invention results from the further realization that by segmenting the detector, ion detection may be achieved with greater accuracy and resolution by detecting ions spatially according to the ions' trajectories as the ions exit the filter.

This invention features a micromechanical field asymmetric ion mobility filter for a detection system. There is a pair of spaced substrates defining between them a flow path between a sample inlet and an outlet, an ion filter disposed in the path and including a pair of spaced filter electrodes, one electrode associated with each substrate and an electrical controller for applying a bias voltage and an asymmetric periodic voltage across the ion filter electrodes for controlling the paths

of ions through the filter.

In a preferred embodiment there may be a detector, downstream from the ion filter, for detecting ions that exit the filter. The detector may include a plurality of segments, the segments separated along the flow path to spatially separate the ions according to their trajectories. There may be confining electrodes, responsive to the electrical controller, for concentrating selected ions as they pass through the filter. The confining electrodes may be silicon. The silicon electrodes may act as spaces for spacing the substrates. There may be a heater for heating the flow path. The heater may include the ion filter electrodes. The electrical controller may include means for selectively applying a current through the filter electrodes to heat the filter electrodes. The substrate may be glass. The glass may be Pyrex®. There may be an ionization source, upstream from the filter, for ionizing a fluid flow from the sample inlet. The ionization source may include a radioactive source. The ionization source may include an ultraviolet lamp. The ionization source may include a corona discharge device. There may be a clean air inlet for introducing purified air into the flow path. There may be a pump in communication with the flow path, for regulating a fluid flow through the flow path.

The invention also features a field asymmetric ion mobility filter and detection system. There is a housing having a flow path between a sample inlet and an outlet, an ion filter disposed in the flow path and including a pair of spaced filter electrodes, an electrical controller for applying a bias voltage and an asymmetric periodic voltage across the ion filter electrodes for controlling the path of ions

through the filter, and a segmented detector, downstream from the ion filter, its segments separated along the flow path to spatially separate the ions according to their trajectories.

In a preferred embodiment there may be confining electrodes, responsive to the electrical controller, for concentrating the ions as they pass through the filter. The confining electrode may be silicon. The silicon electrodes may act as a spacer for spacing the filter electrodes. There may be a heater for heating the flow path. The heater may include the ion filter electrodes. The electrical controller may include means for selectively applying current through the filter electrodes to heat the filter electrodes. There may be an ionization source upstream from the filter for ionizing fluid flow from the sample inlet. The ionization source may include a radioactive source. The ionization source may include an ultraviolet lamp. The ionization source may include a corona discharge device. There may be a clean air inlet for introducing purified air into the flow path. There may be a pump in communication with the flow path for regulating a fluid flow through the flow path.

The invention also features a field asymmetric ion mobility filter array. There is a housing defining at least one flow path between a sample inlet and an outlet, a plurality of ion filters disposed within the housing, each ion filter including a pair spaced filter electrodes, and an electrical controller for applying a bias voltage and an asymmetric periodic voltage across each pair of ion filter electrodes for controlling the path of ions through each filter.

In a preferred embodiment each ion filter may be associated with one of the

flow paths. There may be a detector downstream from each ion filter for detecting ions that exit each said filter. Each detector may include a plurality of segments, the segments separated along the flow path to spatially separate the ions according to their trajectories. There may be a plurality of confining electrodes, responsive to the electrical controller, for concentrating the ions as they pass through each filter. Each confining electrode may be silicon. The silicon electrode may act as a spacer for spacing the filter electrodes. There may be a heater for heating the at least one flow path. The heater may include each pair of ion filter electrodes. The electrical controller may include means for selectively applying a current through each pair of filter electrodes to heat the filter electrodes. There may be an ionization source upstream from each filter for ionizing a fluid flow from the sample inlet. The ionization source may be a radioactive source. The ionization source may be an ultraviolet lamp. The ionization source may be a corona discharge device. There may be a clean air inlet for introducing purified air into the at least one flow path. There may be a pump in communication with each flow path for regulating a fluid flow through each flow path.

The invention also features an uncompensated field asymmetric ion mobility filter for a detection system. There is a housing having a flow path between a sample inlet and an outlet, an ion filter disposed in the path and including a pair of spaced filter electrodes, an electrical controller for applying an uncompensated asymmetric periodic voltage across the ion filter for controlling the path of ions through the ion filter, and a selection circuit for selectively adjusting the duty cycle of the periodic

voltage to target a selected specie or species of ion to be detected.

In a preferred embodiment there may be a detector downstream from the ion filter for detecting ions that exit the filter. The detector may include a plurality of segments, the segments separated along the flow path to spatially separate the ions according to their trajectories. There may be a confining electrode, responsive to the electrical controller, for concentrating the ions as they pass through the filter. The confining electrode may be silicon. The silicon electrode may act as a spacer for spacing the filter electrodes. There may be a heater for heating the flow path. The heater may include the ion filter electrodes. The electrical controller may include means for selectively applying a current through the filter electrodes to heat the filter electrodes. There may be an ionization source, upstream from the filter, for ionizing a fluid flow from sample inlet. The ionization source may include a radioactive source. The ionization source may include an ultraviolet lamp. The ionization source may include a corona discharge device. There may be a clean air inlet for introducing purified air into the flow path. There may be a pump in communication with the flow path for regulating a fluid flow through the flow path.

The invention also features a field asymmetric ion mobility filter. There is a housing having a flow path between a sample inlet and an outlet, an ion filter disposed in the flow path and including a pair of spaced filter electrodes, a pair of confining electrodes transverse to the flow path, and an electrical controller for applying a first bias voltage and an asymmetric periodic voltage across the ion filter electrodes and for applying a second bias voltage across the confining electrodes for

controlling the path of ions through the filter.

In a preferred embodiment there may be a detector downstream from the ion filter for detecting ions that exit the filter. The detector may include a plurality of segments, the segments separated along the flow path to spatially separate the ions according to their trajectories. The confining electrodes may be silicon. The silicon electrodes may act as a spacer for spacing the filter electrodes. There may be a heater for heating the flow path. The heater may include the ion filter electrodes. The heater may include the confining electrodes. The electrical controller may include means for selectively applying a current through the filter electrodes to heat the filter electrodes. The electrical controller may include means for selectively applying a current through the confining electrodes to heat the confining electrodes. There may be an ionization source upstream from the filter for ionizing fluid flow from the sample inlet. The ionization source may include a radiation source. The ionization source may include an ultraviolet lamp. The ionization source may be a corona discharge device. There may be a clean air inlet for introducing purified air into the flow path. There may be a pump in communication with the flow path for regulating a fluid flow through the flow path.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects, features and advantages will occur to those skilled in the art from the following description of a preferred embodiment and the accompanying drawings, in which:

Fig. 1 is a schematic block diagram of the micromachined filter and detection system according to the present invention;

Fig. 2 is a schematic representation of the ions as they pass through the filter electrodes of Fig. 1 toward the detector;

Fig. 3A is a graphical representation of the bias voltage required to detect acetone and the sensitivity obtainable;

Fig. 3B is a representation, similar to Fig. 3A, of the bias voltage required to detect Diethyl methyl amine;

Fig. 4 is a cross sectional of the view of the spaced, micromachined filter according to the present invention;

Fig. 5 is a three dimensional view of the packaged micromachined filter and detection system, including fluid flow pumps, demonstrating the miniaturized size which maybe realized;

Fig. 6 is an exploded view of one embodiment according to the present invention in which an array of filters and detectors are disposed in a single flow path;

Fig. 7 is an exploded view, similar to Fig. 6, in which the array of filters is stacked and one filter and detector is associated with a single flow path.

Fig. 8 is a cross sectional representation of a single flow path of the arrayed filter and detector system of Fig. 7;

Fig. 9 is graphical representation demonstrating simultaneous multiple detections of benzene and acetone;

Fig. 10 is a schematic block diagram, similar Fig. 1, in which the filter is not

compensated by a bias voltage and the duty cycle of the periodic voltage is instead varied to control the flow of ions through the filter;

Fig. 11 is a graphical representation of an asymmetric periodic voltage having a varying duty cycle which is applied to the filter of Fig. 9 to filter selected ions without a bias voltage; and

Fig. 12 is a schematic diagram of a filter and detector system in which the detector is segmented to spatially detect ions as they exit the filter.

PREFERRED EMBODIMENT

FAIM spectrometer 10, Fig. 1, operates by drawing a gas, indicated by arrow 12, via pump 14, through inlet 16 into ionization region 18. The ionized gas is passed between parallel electrode plates 20 and 22, which comprise ion filter 24, following flow path 26. As the gas ions pass between plates 20 and 22, they are exposed to an asymmetric oscillating electric field between electrode plates 20 and 22 induced by a voltage applied to the plates by voltage generator 28 in response to electronic controller 30.

As ions pass through filter 24, some are neutralized by plates 20 and 22 while others pass through and are sensed by detector 32. Detector 32 includes a top electrode 33 at a predetermined voltage and a bottom electrode 35, typically at ground. Top electrode 33 deflects ions downward to electrode 35. However, either electrode may detect ions depending on the ion and the voltage applied to the electrodes. Moreover, multiple ions may be detected by using top electrode 33 as

one detector and bottom electrode 35 as a second detector. Electronic controller 30 may include, for example, amplifier 34 and microprocessor 36. Amplifier 34 amplifies the output of detector 32, which is a function of the charge collected by detector 34, and provides the output to microprocessor 36 for analysis. Similarly, amplifier 34', shown in phantom, may be provided where electrode 33 is also utilized as a detector.

As ions 38, Fig. 2, pass through alternating asymmetric electric field 40, which is transverse to gas flow 12, electric field 40 causes the ions to "wobble" along paths 42a, 42b and 42c. Field 40 is typically in the range of $\pm (1000-2000)$ volts dc and has a maximum field strength of 40,000 V/cm. The path taken by a particular ion is a function of its mass, size, cross-section and charge. Once an ion reaches electrode 20 or 22, it is neutralized. A second, bias or compensation field 44, typically in the range of ± 2000 V/cm or ± 100 volts dc, is concurrently induced between electrodes 20 and 22 by a bias voltage applied to plates 20 and 22, also by voltage generator 28, Fig. 1, in response to microprocessor 36 to enable a preselected ion species to pass through filter 24 to detector 32. Compensation field 44 is a constant bias which offsets alternating asymmetric field 40 to allow the preselected ions, such as ion 38c to pass to detector 32. Thus, with the proper bias voltage, a particular species of ion will follow path 42c while undesirable ions will follow paths 42a and 42b to be neutralized as they encounter electrode plates 20 and 22.

The output of FAIM spectrometer 10 is a measure of the amount of charge

on detector 32 for a given bias voltage 44. The longer filter 24 is set at a given compensation bias voltage, the more charge will accumulate on detector 32. However, by sweeping compensation voltage 44 over a predetermined voltage range, a complete spectrum for sample gas 12 can be achieved. The FAIM spectrometer according to the present invention requires typically less than thirty seconds and as little as one second to produce a complete spectrum for a given gas sample.

By varying compensation bias voltage 44 the species to be detected can be varied to provide a complete spectrum of the gas sample. For example, with a bias voltage of -3.5 volts acetone was detected as demonstrated by concentration peaks 46, Fig. 3A in concentrations as low as 83 parts per billion. In contrast, at a bias voltage of -6.5 volts, diethyl methyl amine, peaks 48, Fig. 3B, was detected in concentrations as low as 280 parts per billion.

Filter 24, Fig. 4, is on the order of one inch in size. Spectrometer 10 includes spaced substrates 52 and 54, for example glass such as Pyrex® available from Corning Glass, Corning, N.Y., and electrodes 20 and 22, which may be for example gold, titanium, or platinum, mounted or formed on substrates 52 and 54, respectively. Substrates 52 and 54 are separated by spacers 56a and 56b which may be formed by etching or dicing silicon wafer. The thickness of spacers 56a-b defines the distance between electrodes 20 and 22. Moreover, applying the same voltage to silicon spacers 56a-b, typically \pm (10-1000 volts dc) transforms spacers

56a and 56b into electrodes which produce a confining electric field 58, which guides or confines the ions' paths to the center of flow path 26, Fig. 1, in order to obtain a better sample spectrum. To confine the ions, spacer electrodes 56a-b must be at the same voltage so as to "push" the ions to the center of flow path 26. This increases the sensitivity of the system by preserving more ions so that more ions strike detector 34. However, this is not a necessary limitation of the invention.

To maintain accurate and reliable operation of spectrometer 10, neutralized ions which accumulate on electrode plates 20 and 22 must be purged. This may be accomplished by heating flow path 26. For example, controller 30, Fig. 1, may include current source 29, shown in phantom, which provides, in response to microprocessor 36, a current I to electrode plates 20 and 22 to heat the plates, removing accumulated molecules. Similarly, current I may instead be applied to spacer electrodes 56a and 56 b, Fig. 4, to heat flow path 26 and clean plates 20 and 22.

Packaged FAIM spectrometer 10, Fig. 5, may be reduced in size to one inch by one inch by one inch. Pump 14 is mounted on substrate 52 for drawing a gas sample 12 into inlet 16. Clean dry air may be introduced into flow path 26, Fig. 1, by recirculation pump 14a prior to or after ionization of the gas sample. Electronic controller 30 may be etched into silicon control layer 60 which combines with substrates 52 and 54 to form a housing for spectrometer 10. Substrates 52 and 54 and control layer 60 may be bonded together, for example, using anodic bonding, to provide an extremely small FAIM spectrometer. Micro pumps 14 and 14a provide

a high volume throughput which further expedites the analysis of gas sample 12.

Pumps 14 and 14a may be, for example, conventional miniature disk drive motors fitted with small centrifugal air compressor rotors or micromachined pumps, which produce flow rates of 1 to 4 liters per minute. One example of pump 14 is available from Sensidyne, Inc., Clearwater, Florida.

While the FAIM spectrometer according to the present invention quickly produces a spectrum for a particular gas sample, the time for doing so may be further reduced with an array of filters 32. FAIM spectrometer 10, Fig. 6, may include filter array 62, a single inlet 16 and single flow path 26. Sample gas 12 is guided by confining electrodes 56a-h to filter array 62 after passing by ionization source 18, which may include an ultraviolet light source, a radioactive device or corona discharge device. Filter array 62 includes, for example, paired filter electrodes 20a-e and 22a-e and may simultaneously detect different ion species by applying a different compensation bias voltage 44, Fig. 2, to each electrode pair and sweeping each electrode pair over a different voltage range greatly reducing the sweep time. However, array 62 may include any number of filters depending on the size of the spectrometer. Detector array 64, which includes detectors 32a-e, detects multiple selected ion species simultaneously, thereby reduce the time necessary to obtain a spectrum of the gas sample 12. The electrode pairs share the same asymmetric periodic ac voltage 40.

Clean dry air may be introduced into flow path 26 through clean air inlet 66 via recirculator pump 14a, Fig. 5. Drawing in clean dry air assists in reducing the

FAIM spectrometer's sensitivity to humidity. Moreover, if the spectrometer is operated without clean dry air and a known gas sample is introduced into the device, the device can be used as a humidity sensor since the resulting spectrum will change with moisture concentration from the standardized spectrum for the given sample.

However, rather than each filter 32a-e of filter array 62 sharing the same flow path 26, individual flow paths 26a-e, Fig. 7, may be provided so that each flow path has associated with it, for example, inlet 16a, ionization region 18a, confining electrodes 56a', 56b', ion filter electrode pair 20a, 22a, detector electrode pair 33a, 35a and exit port 68a.

In operation, sample gas 12 enters sample inlet 16a, Fig. 8, and is ionized by, for example, a corona discharge device 18a. The ionized sample is guided towards ion filter 24a by confining electrodes 56a. As ions pass between ion filter electrodes 20a and 22a, undesirable ions will be neutralized while selected ions will pass through filter 24a to be detected by detector 32a.

As shown in Fig. 9, multiple, simultaneous detections were made of Benzene, peaks 50 and acetone peaks 51, demonstrating the advantage of the arrayed filters and detectors according to the present invention.

It has also been found that a compensation bias voltage is not necessary to detect a selected specie or species of ion. By varying the duty cycle of the asymmetric periodic voltage applied to electrodes 20 and 22 of filter 24, Fig. 10, there is no need to apply a constant bias voltage to plate electrodes 20 and 22.

Voltage generator 28, in response to control electronics 30 varies the duty cycle of asymmetric alternating voltage 40. By varying the duty cycle of periodic voltage 40, Fig. 11, the path of selected ion 32c may be controlled. As an example, rather than a limitation, the duty cycle of field 40 may be one quarter: 25% high, peak 70, and 75% low, valley 72, and ion 38c approaches plate 20 to be neutralized. However, by varying the duty cycle of voltage 40a to 40%, peak 70a, ion 38c passes through plates 20 and 22 without being neutralized. Typically the duty cycle is variable from 10-50% high and 90-50% low. Accordingly, by varying the duty cycle of field 40, an ion's path may be controlled without the need of a bias voltage.

To improve FAIM spectrometry resolution even further, detector 32, Fig. 12, may be segmented. Thus, as ions pass through filter 24 between filter electrodes 20 and 22, the individual ions 38c'-38c''' may be detected spatially, the ions having their trajectories 42c'-42c''' determined according to their size, charge and cross section. Thus detector segment 32' will have one a concentration of one species of ion while detector segment 32'' will have a different ion species concentration, increasing the spectrum resolution as each segment may detect a particular ion species.

Although specific features of the invention are shown in some drawings and not in others, this is for convenience only as each feature may be combined with any or all of the other features in accordance with the invention.

Other embodiments will occur to those skilled in the art and are within the

following claims:

What is claimed is:

CLAIMS

1. A micromechanical field asymmetric ion mobility filter for a detection system comprising:

a pair of spaced substrates defining between them a flow path between a sample inlet and an outlet;

an ion filter disposed in the path and including a pair of spaced filter electrodes, one electrode associated with each substrate; and

an electrical controller for applying a bias voltage and an asymmetric periodic voltage across the ion filter electrodes for controlling the paths of ions through the filter.

2. The micromechanical filter of claim 1 further including a detector, downstream from the ion filter, for detecting ions that exit the filter.

3. The micro mechanical filter of claim 2 in which the detector includes a plurality of segments, the segments separated along the flow path to spatially separate the ions according to their trajectories.

4. The micro mechanical filter of claim 1 further including a confining electrodes, responsive to the electrical controller, for concentrating selected ions as they pass through the filter.

5. The micro mechanical filter of claim 4 in which the confining electrode is silicon.

6. The micro mechanical filter of claim 5 in which the silicon electrode acts as a spacer for spacing said substrate.

7. The micro mechanical filter of claim 1 further including a heater for heating the flow path.

8. The micro mechanical filter of claim 7 in which the heater includes the ion filter electrodes.

9. The micro mechanical filter of claim 8 in which the electrical controller further includes means for selectively applying a current through the filter electrodes to heat the filter electrodes.

10. The micro mechanical filter of claim 1 in which the substrate is glass.

11. The micro mechanical filter of claim 10 in which the glass is Pyrex®.

12 The micro mechanical filter of claim 1 further including an ionization source, upstream from the filter, for ionizing a fluid flow from the sample inlet.

13. The micro mechanical filter of claim 12 in which the ionization source includes a radiation source.

14. The micro mechanical filter of claim 12 in which the ionization source includes an ultraviolet lamp.

15. The micro mechanical filter of claim 12 in which the ionization source includes a corona discharge device.

16. The micro mechanical filter of claim 1 further including a clean air inlet for introducing purified air into the flow path.

17. The micro mechanical filter of claim 1 further including a pump in communication with the flow path, for regulating a fluid flow through the flow path.

18. A field asymmetric ion mobility filter and detection system comprising:

a housing having a flow path between a sample inlet and an outlet;

an ion filter disposed in the flow path and including a pair of spaced filter electrodes;

an electrical controller for applying a bias voltage and an asymmetric periodic voltage across the ion filter electrodes for controlling the path of ions through the filter; and

a segmented detector, downstream from the ion filter, its segments separated along the flow path to spatially separate the ions according to their trajectories.

19. The field asymmetric ion mobility filter and detection system of claim 18 further including confining electrodes, responsive to the electrical controller, for concentrating the ions as they pass through the filter.

20. The field asymmetric ion mobility filter and detection system of claim 19 in which the confining electrode is silicon.

21. The field asymmetric ion mobility filter and detection system of claim 20 in which the silicon electrode acts as a spacer for spacing the substrate.

22. The field asymmetric ion mobility filter and detection system of claim 18 further including a heater for heating the flow path.

23. The field asymmetric ion mobility filter and detection system of claim 22 in which the heater includes the ion filter electrodes.

24. The field asymmetric ion mobility filter and detection system of claim 23 in which the electrical controller further includes means for selectively applying current through the filter electrodes to heat the filter electrodes.

25. The field asymmetric ion mobility filter and detection system of claim 18 further including an ionization source upstream from the filter for ionizing fluid flow from the sample inlet.

26. The field asymmetric ion mobility filter and detection system of claim 25 in which the ionization source includes a radioactive source.

27. The field asymmetric ion mobility filter and detection system of claim 25 in which the ionization source includes an ultraviolet lamp.

28. The field asymmetric ion mobility filter and detection system of claim 25 in which the ionization source includes a corona discharge device.

29. The field asymmetric ion mobility filter and detection system of claim 18 further including a clean air inlet for introducing purified air into the flow path.

30. The field asymmetric ion mobility filter and detection system of claim 18 further including a pump in communication with the flow path for regulating a fluid flow through the flow path.

31. A field asymmetric ion mobility filter array comprising:
a housing defining at least one flow path between a sample inlet and an outlet;
a plurality of ion filters disposed within the housing, each ion filter including a pair spaced filter electrodes; and
an electrical controller for applying a bias voltage and an asymmetric periodic voltage across each said pair of ion filter electrodes for controlling the path of ions through each said filter.

32. The filter array of claim 31 in which each said ion filter is associated with one of the flow paths.

33. The filter array of claim 31 further including a detector downstream from each said ion filter for detecting ions that exit each said filter.

34. The filter array of claim 33 in which each said detector includes a plurality of segments, the segments separated along the flow path to spatially separate the ions according to their trajectories.

35. The filter array of claim 31 further including a plurality of confining electrodes, responsive to the electrical controller, for concentrating the ions as they pass through each said filter.

36. The filter array of claim 35 in which each said confining electrode is silicon.

37. The filter array of claim 36 in which the silicon electrode acts as a spacer for spacing the filter electrodes.

38. The filter array of claim 31 further including a heater for heating said at least one flow path.

39. The filter array of claim 38 in which the heater includes each said pair of ion filter electrodes.

40. The filter array of claim 38 in which the electrical controller further includes means for selectively applying a current through each said pair of filter electrodes to heat the filter electrodes.

41. The filter array of claim 31 further including an ionization source upstream from each said filter for ionizing a fluid flow from the sample inlet.

42. The filter array of claim 41 in which the ionization source includes a radioactive source.

43. The filter array of claim 41 in which the ionization source includes an ultraviolet lamp.

44. The filter array of claim 41 in which the ionization source includes a corona discharge device.

45. The filter array of claim 31 further including a clean air inlet for introducing purified air into said at least one flow path.

46. The filter array of claim 31 further including a pump in communication with each said flow path for regulating a fluid flow through each said flow path.

47. An uncompensated field asymmetric ion mobility filter for a detection system comprising:

a housing having a flow path between a sample inlet and an outlet;

an ion filter disposed in the path and including a pair of spaced filter electrodes;

an electrical controller for applying an uncompensated asymmetric periodic voltage across the ion filter for controlling the path of ions through the ion filter; and

a selection circuit for selectively adjusting the duty cycle of the periodic voltage to target a selected specie or species of ion to be detected.

48. The ion mobility filter of claim 47 further including a detector downstream from the ion filter for detecting ions that exit the filter.

49. The ion mobility filter of claim 48 in which the detector includes a plurality of segments, the segments separated along the flow path to spatially separate the ions according to their trajectories.

50. The ion mobility filter of claim 48 further including a confining electrode, responsive to the electrical controller, for concentrating the ions as they pass through the filter.

51. The ion mobility filter of claim 50 in which the confining electrode is silicon.

52. The ion mobility filter of claim 51 in which the silicon electrode acts as a spacer for spacing the filter electrodes.

53. The ion mobility filter of claim 47 further including a heater for heating the flow path.

54. The ion mobility filter of claim 51 in which the heater includes the ion filter electrodes.

55. The ion mobility filter of claim 54 in which the electrical controller further includes means for selectively applying a current through the filter electrodes to heat the filter electrodes.

56. The ion mobility filter of claim 47 further including an ionization source upstream, from the filter, for ionizing a fluid flow from sample inlet.

57. The ion mobility filter of claim 56 in which the ionization source includes a radioactive source.

58. The ion mobility filter of claim 56 in which the ionization source includes an ultraviolet lamp.

59. The ion mobility filter of claim 56 in which the ionization source includes a corona discharge device.

60. The ion mobility filter of claim 47 further including a clean air inlet for introducing purified air into the flow path.

61. The ion mobility filter of claim 47 further including a pump in communication with the flow path for regulating a fluid flow through the flow path.

62. A field asymmetric ion mobility filter comprising:
a housing having a flow path between a sample inlet and an outlet;
an ion filter disposed in the flow path and including a pair of spaced filter electrodes;
a pair of confining electrodes transverse to the flow path; and
an electrical controller for applying a first bias voltage and an asymmetric periodic voltage across the ion filter electrodes and for applying a second bias voltage across the confining electrodes for controlling the path of ions through the filter.
63. The filter of claim 62 further including a detector downstream from the ion filter for detecting ions that exit the filter.
64. The filter of claim 63 in which the detector includes a plurality of segments, the segments separated along the flow path to spatially separate the ions according to their trajectories.
65. The filter of claim 62 in which the confining electrodes are silicon.
66. The filter of claim 65 in which the silicon electrodes act as a spacer for spacing the filter electrodes.

67. The filter of claim 62 further including a heater for heating the flow path.

68. The filter of claim 67 in which the heater includes the ion filter electrodes.

69. The filter of claim 67 in which the heater includes the confining electrodes.

70. The filter of claim 68 in which the electrical controller further includes means for selectively applying a current through the filter electrodes to heat the filter electrodes.

71. The filter of claim 68 in which the electrical controller further includes means for selectively applying a current through the confining electrodes to heat the confining electrodes.

72. The filter of claim 62 further including an ionization source upstream from the filter for ionizing fluid flow from the sample inlet.

73. The filter of claim 71 in which the ionization source includes a radioactive source.

74. The filter of claim 71 in which the ionization source includes an ultraviolet lamp.

75. The filter of claim 71 in which the ionization source includes a corona discharge device.

76. The filter of claim 62 further including a clean air inlet for introducing purified air into the flow path.

77. The filter of claim 62 further including a pump in communication with the flow path for regulating a fluid flow through the flow path.

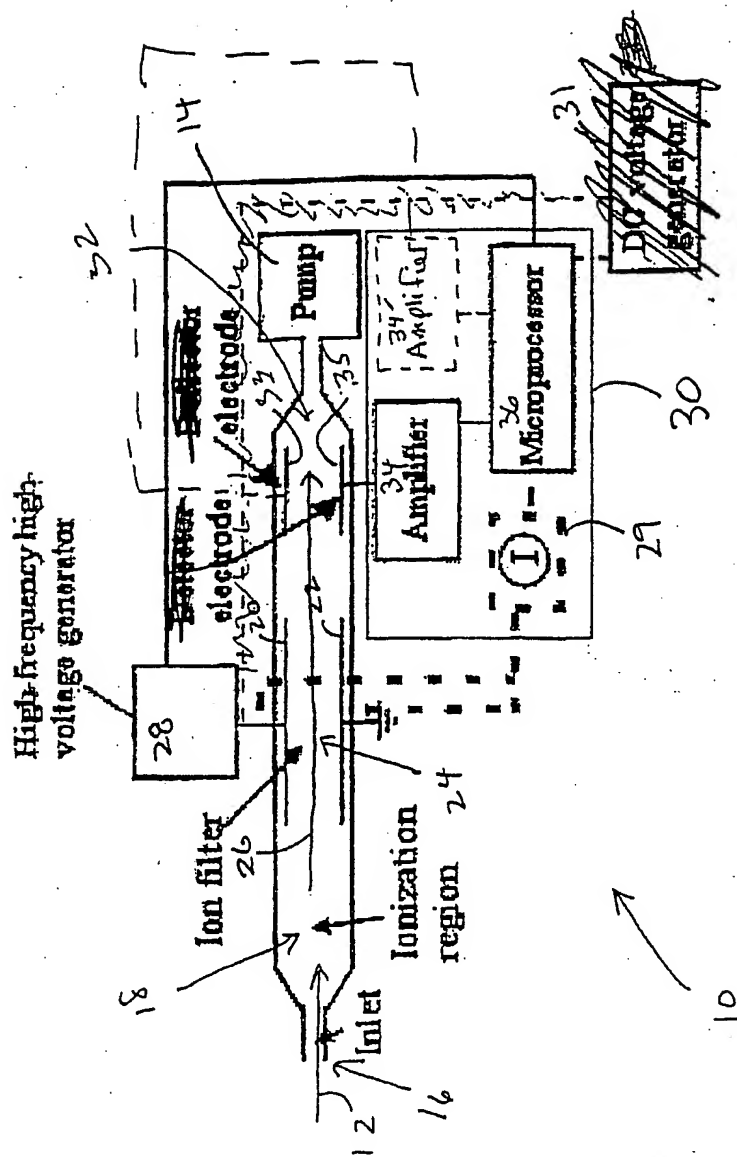


Fig. 1

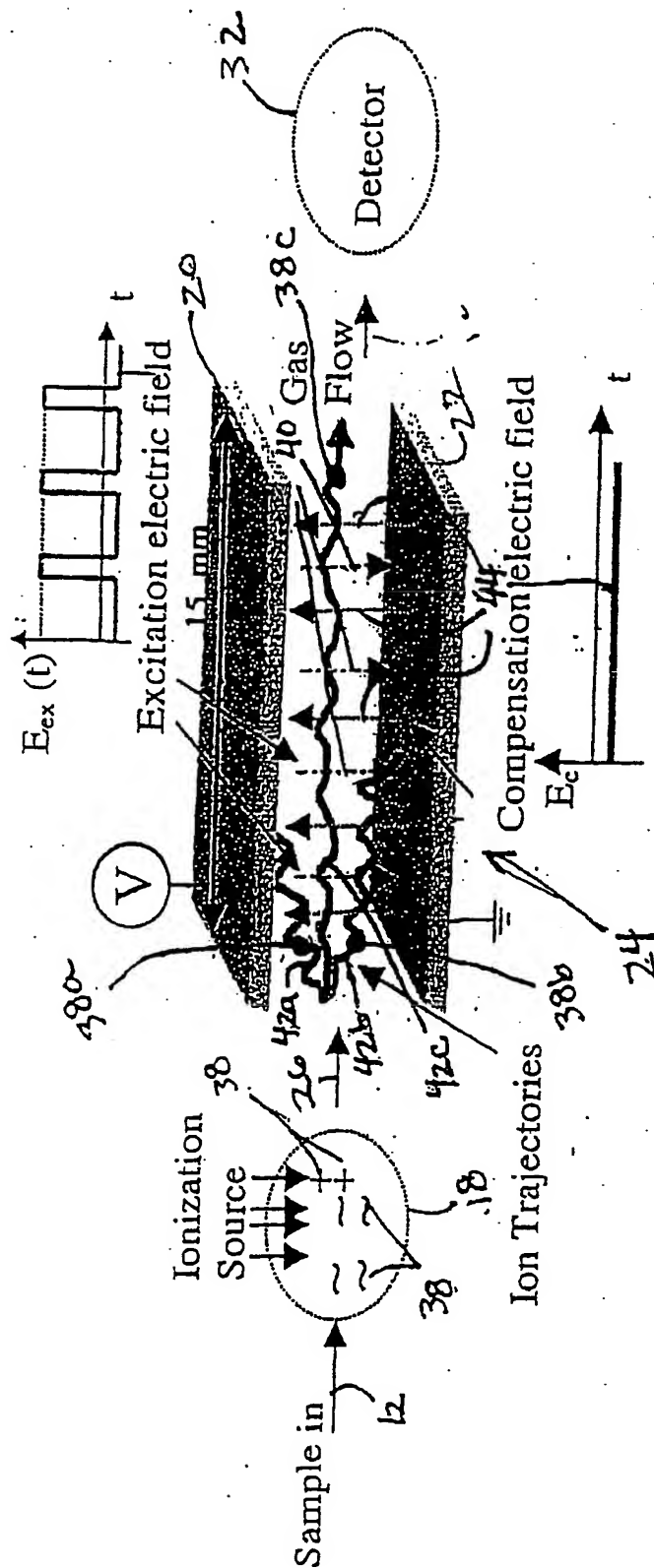


Fig. 2

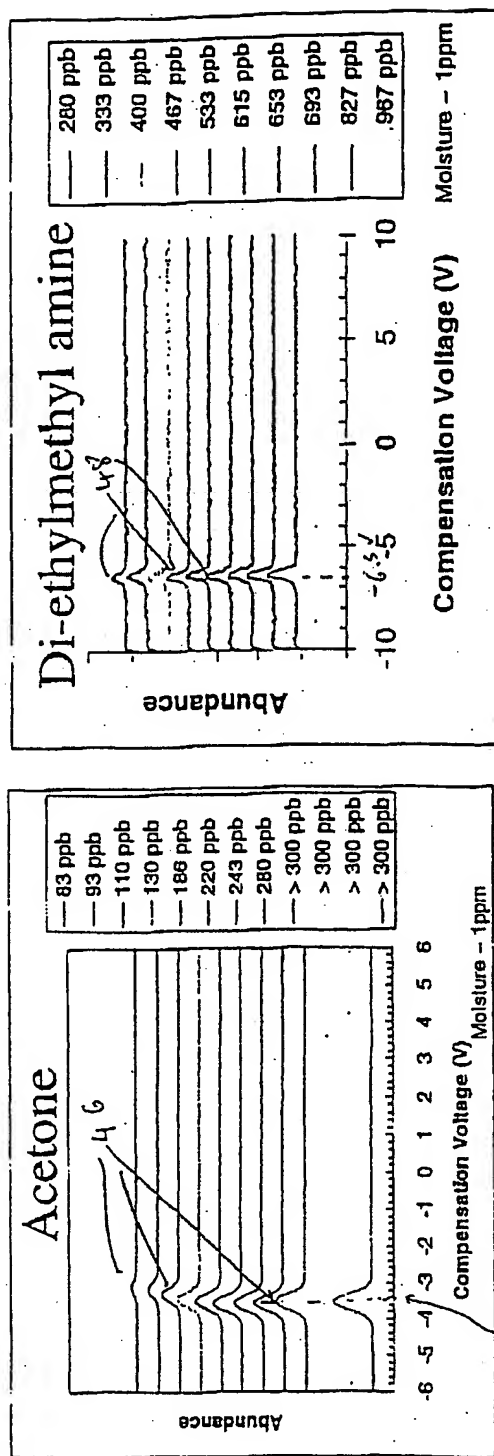
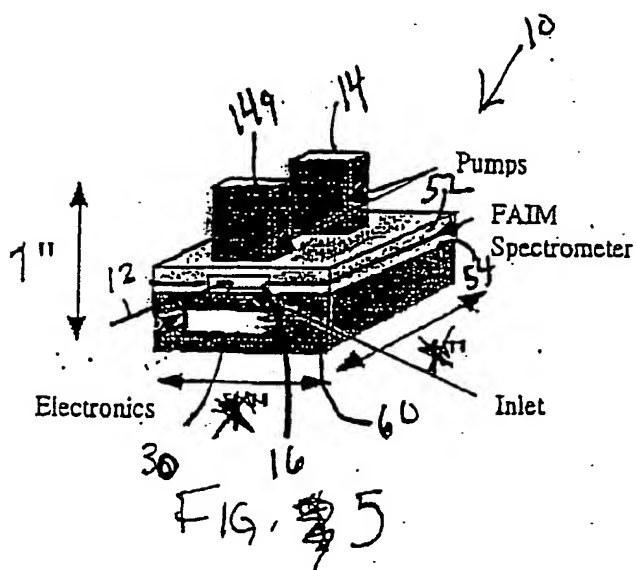
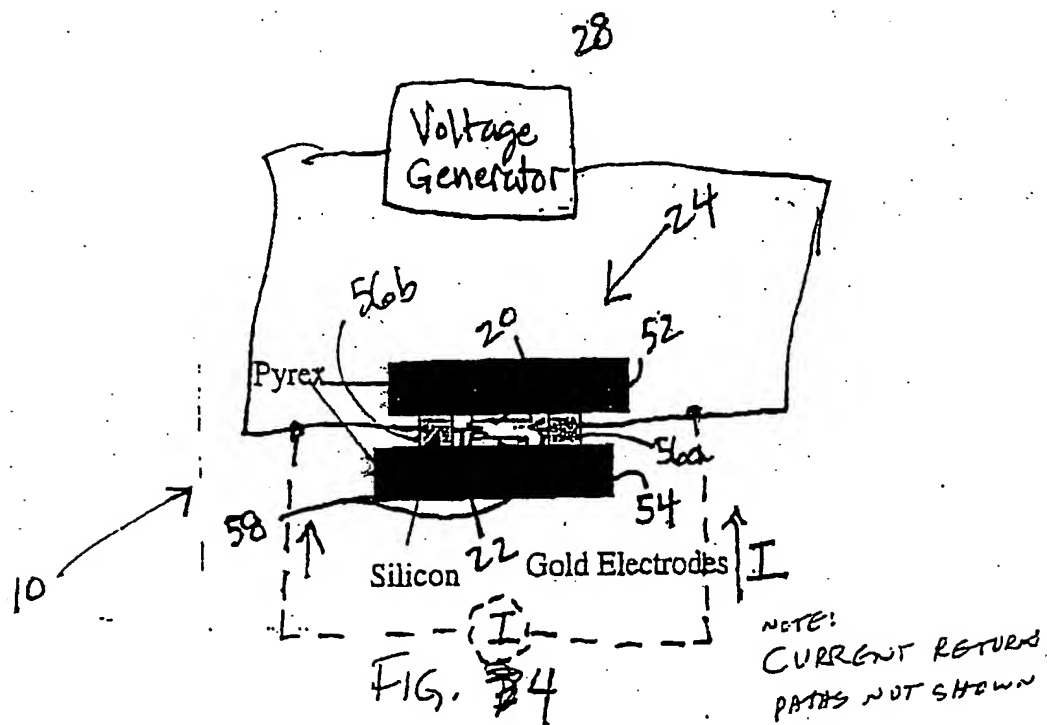
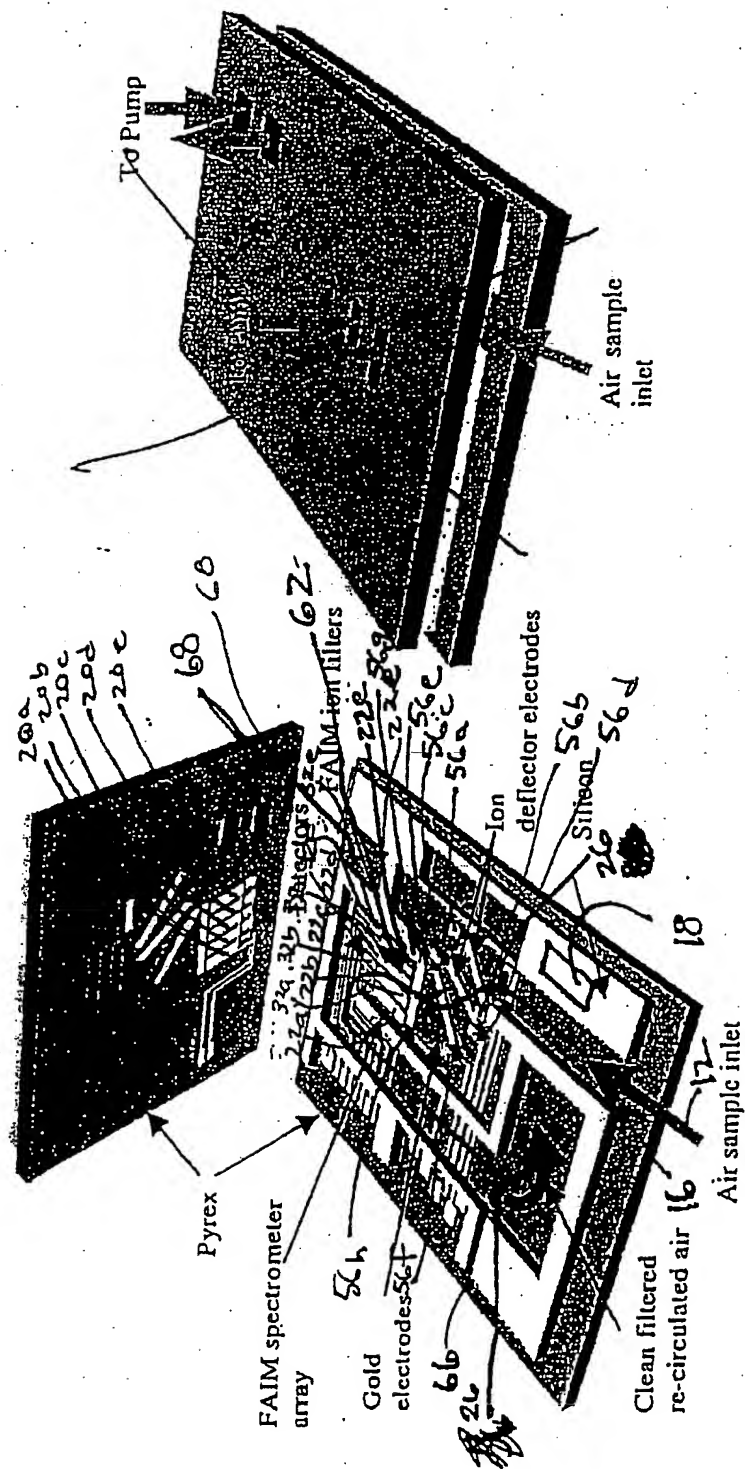


Fig. 3a: Response of FAIM to varying concentrations of Acetone and Di-ethylmethyl amine

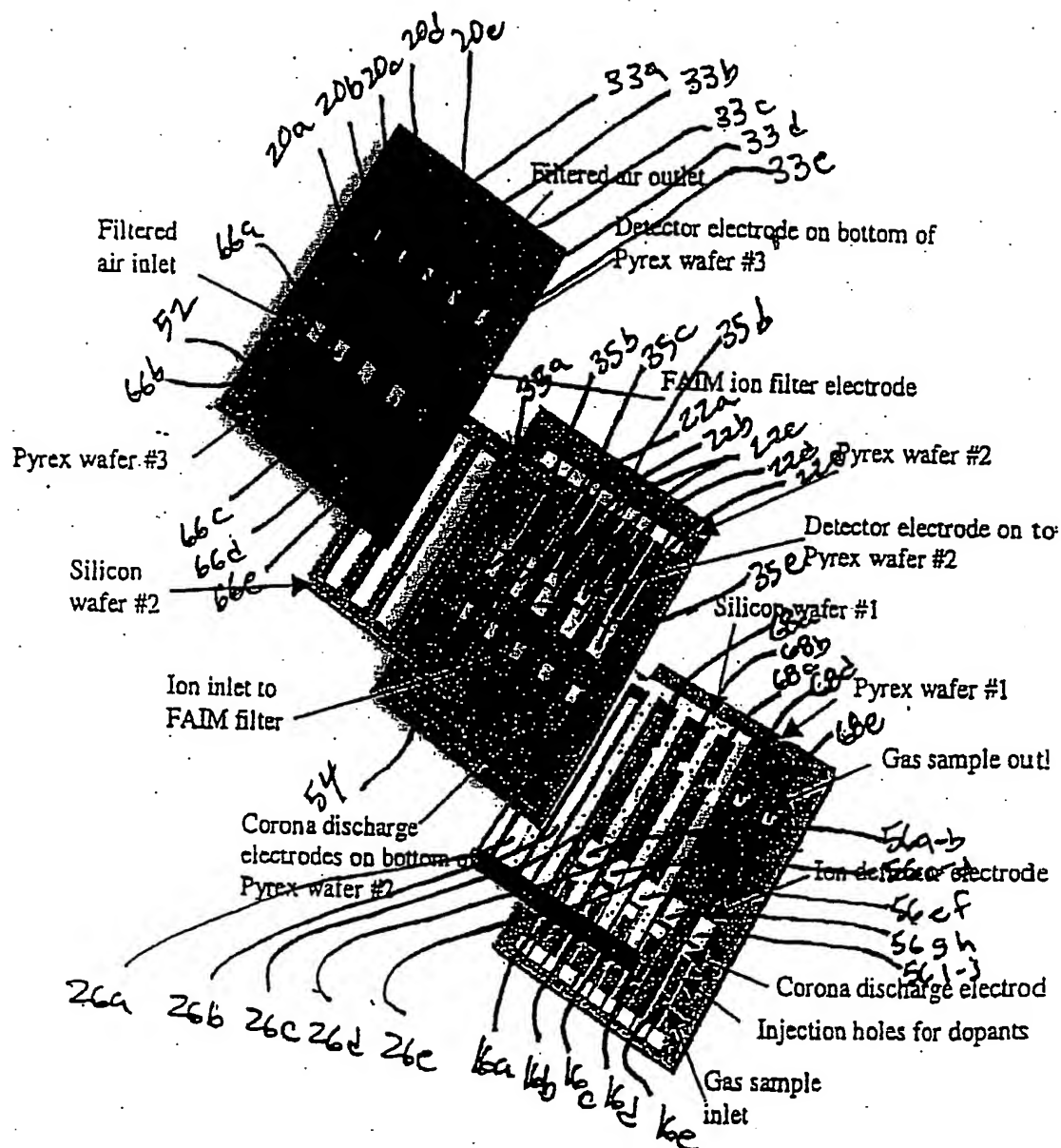




(b)

(a)

Fig. 6



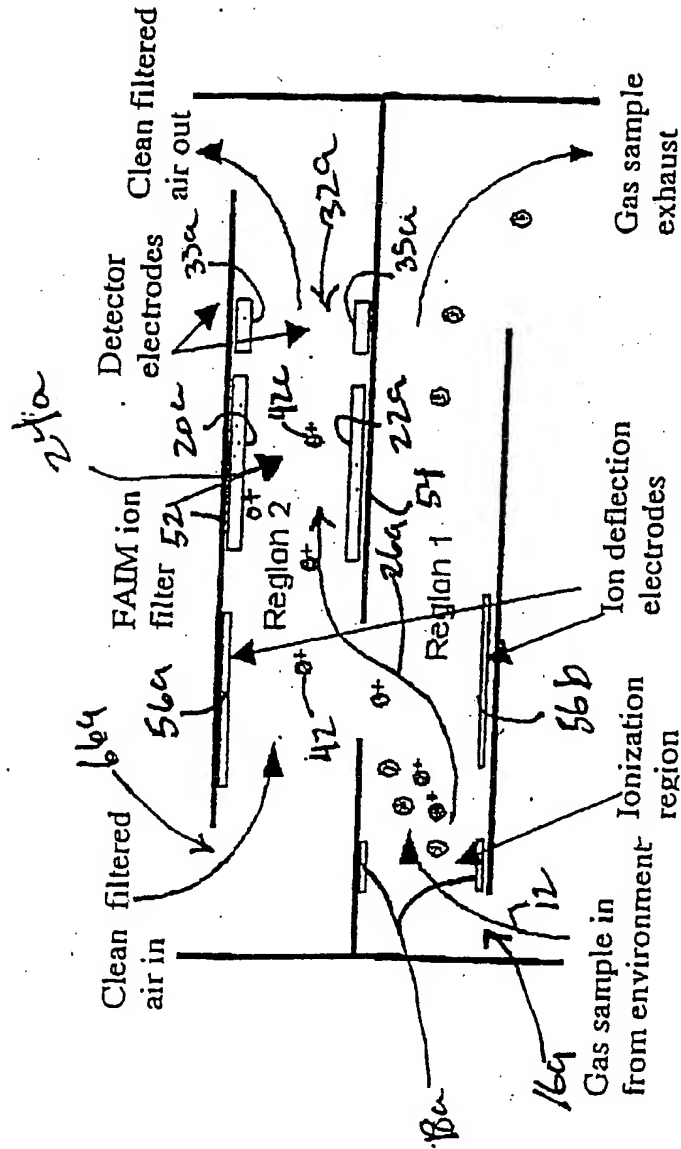


Fig. 8

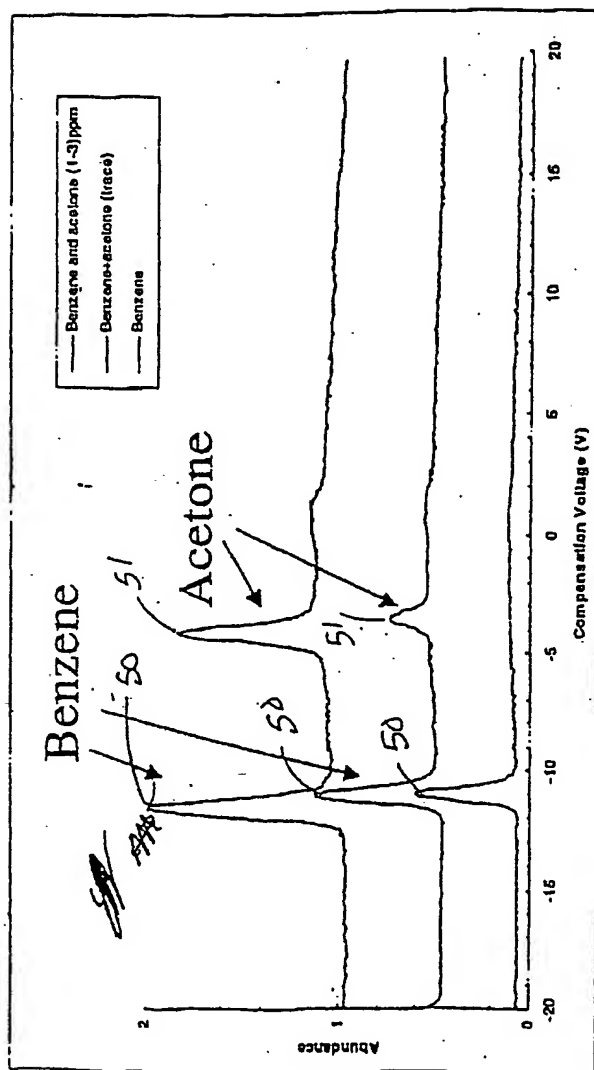


Fig. 3b shows three graphs the top two are for a mixture of acetone and benzene, the bottom is for benzene alone. The graph shows that the acetone peak can be easily distinguished from the benzene peak.

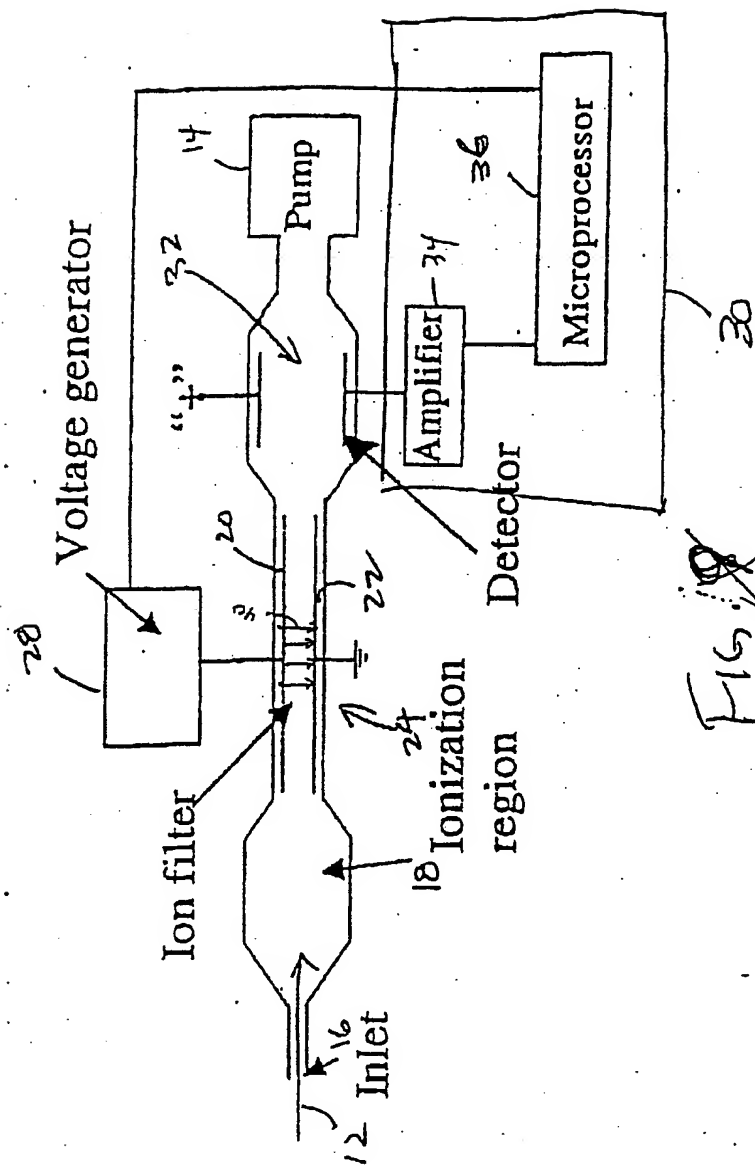


Fig. 10

The figure below shows how the ion trajectory can be altered by changing the excitation voltage duty cycle:

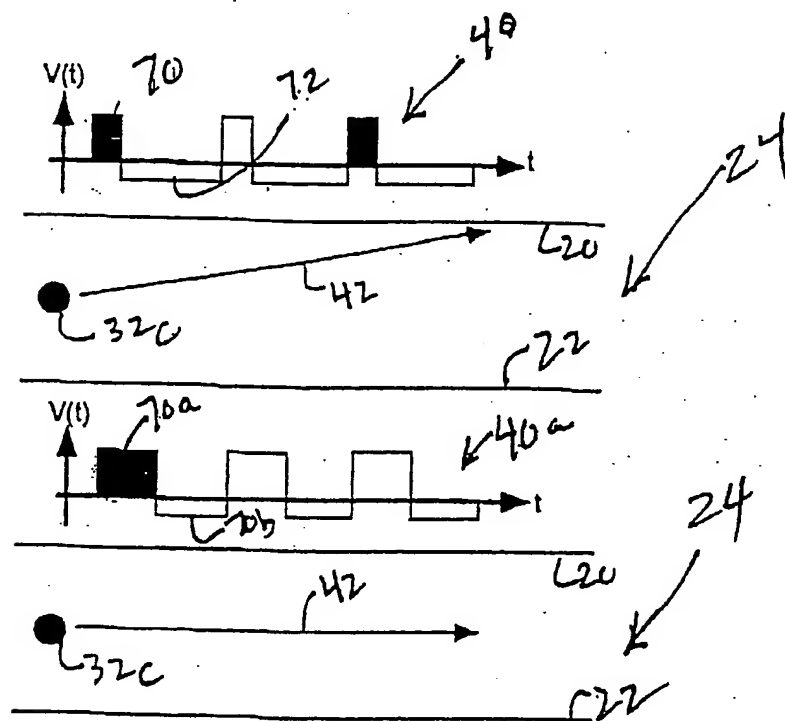


Fig. 11a

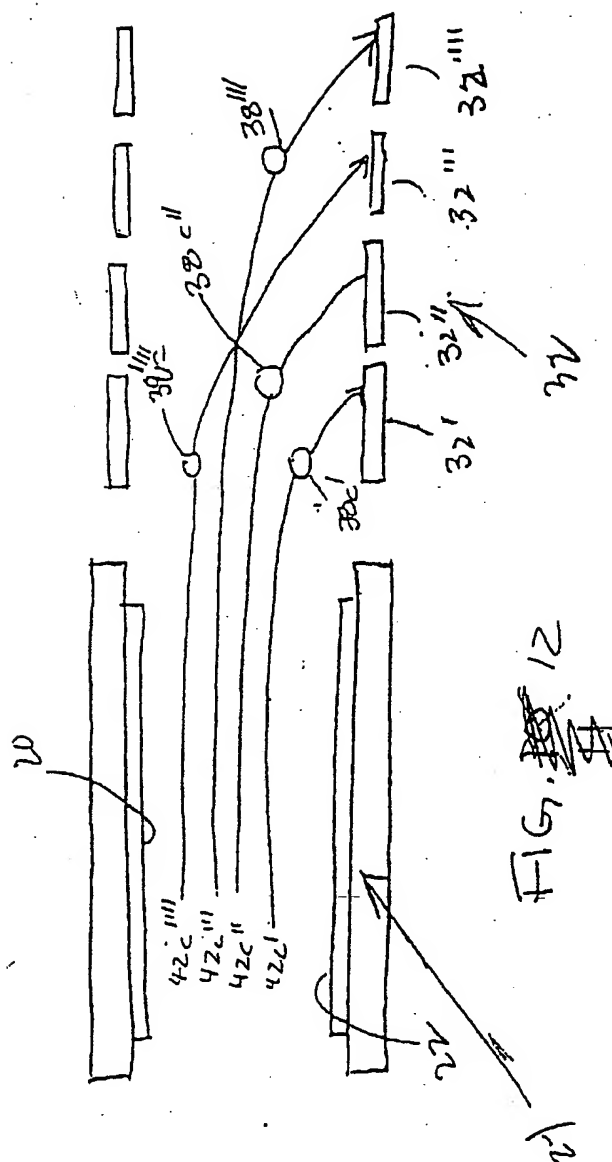


FIG. 12

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/17971

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : H01J 49/00; B01D 59/44

US CL : 250/286, 287

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 250/281, 282, 286, 287, 288

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
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C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|------------|--|--|
| Y | US 5,420,424 A (CARNAHAN et al.) 30 May 1995 (30.05.1995), Abstract, Col. 3, Second Paragraph, Col. 4, Lines 13-47, Col. 8, Lines 20-23, Claims 1 and 6. | 1-4, 10-19, 22, 25-35, 53, 56-65, 67, 71-77 |
| Y,P | US 5,965,882 A (MEGERLE et al.) 12 October 1999 (12.10.1999), Abstract and Claims. | 1-4, 10-19, 22, 25-35, 41-50, 53, 56-65, 67, 71-77 |
| Y | US 5,763,876 A (PERTINARIDES et al.) 09 June 1998 (09.06.1998), claim 5. | 1-4, 10-19, 22, 25-35, 41-50, 53, 56-65, 67, 71-77 |
| Y | US 5,536,939 A (FREIDHOFF ET. AL.) 16 July 1996 (16.07.1996), Figure 2. | 1-4, 10-19, 22, 25-35, 41-50, 53, 56-65, 67, 71-77 |
| A | CARNAHAN et al., FIELD ION SPECTROMETRY - A NEW ANALYTICAL TECHNOLOGY FOR TRACE GAS ANALYSIS, 1996, Paper 96-009, Pages 87-96. Figures 1-2. | 1-77 |

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Date of the actual completion of the international search

15 AUGUST 2000

Date of mailing of the international search report

28 AUG 2000

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